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# Investigation of the effect of upper electrode material on the memristor properties of strained carbon nanotubes

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Silicon technology is used as the basis for the creation of micro- and nanoelectronics storage devices. However, this technology has serious limitations for further miniaturization and reduction of energy consumption. Research is carried out to find an alternative technology for the formation of storage devices. One of the promising directions in this area is the development of memristor structures [1]. Special attention to the creation of memristor structures is attend to vertically aligned carbon nanotubes (VA CNT), which demonstrate high performance and scalability [2]. However, research in this area is at an early stage and requires further research.

The aim of this work is an experimental study of the upper electrode material effect on the memristor properties of carbon nanotubes.

An array of vertically aligned carbon nanotubes grown by PECVD on the lower TiN electrode was used as the test sample. The parameters of the nanotubes were determined using a scanning electron microscope Nova Nanolab 600 and were: diameter 54 ± 6 nm, length 1130 ± 110 nm, density 72 $\mu m^{-2}$ (Fig. 1). Experimental studies were carried out by scanning tunneling microscopy (STM) in current spectroscopy mode at a tunnel gap of 1 nm using a scanning probe microscope Solver (NT-MDT, Russia). STM probes of W, Pt and graphite were used as the upper electrode. Sawtooth voltage pulses with amplitude from ±1 to ±8 V was applied between the STM probe localized on a single VA CNT and the sample. A VA CNT deformation occurred under the action of the local electric field during the measurement [2, 3]. Current-voltage characteristics (CVC) a strained VA CNT obtained from amplitude at ±4 and ±7 V are shown in Figure 2 and 3, respectively.

The analysis of the obtained results showed that the use of a graphite probe as the upper electrode of a VA CNT memristor structure leads to significant decrease a total resistance of the structure at low voltages compared to Pt and W probes (Fig. 2). This is due to the close values of the work function of graphite and VA CNT. However, when increasing the amplitude of the applied voltage to ±7 V or more, degradation of the graphite probe is observed, which is due to its evaporation under the action of high field strength (Fig. 3a). The use of probes made of refractory Pt and W can solve this problem (Fig. 3b,c).

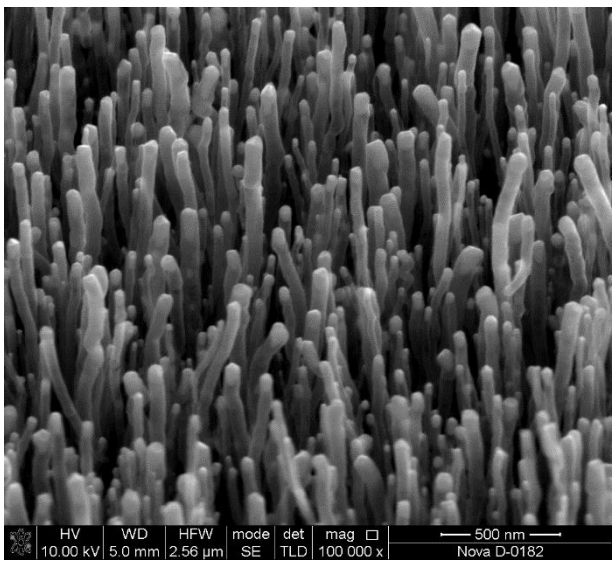
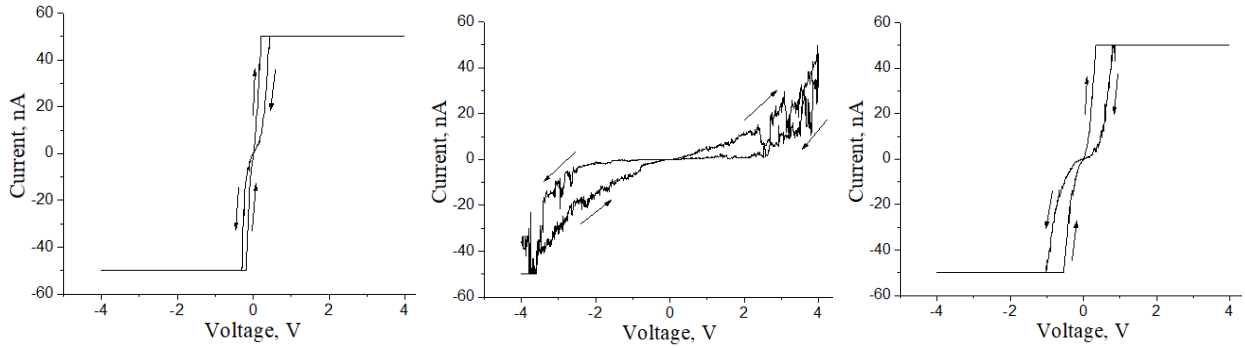
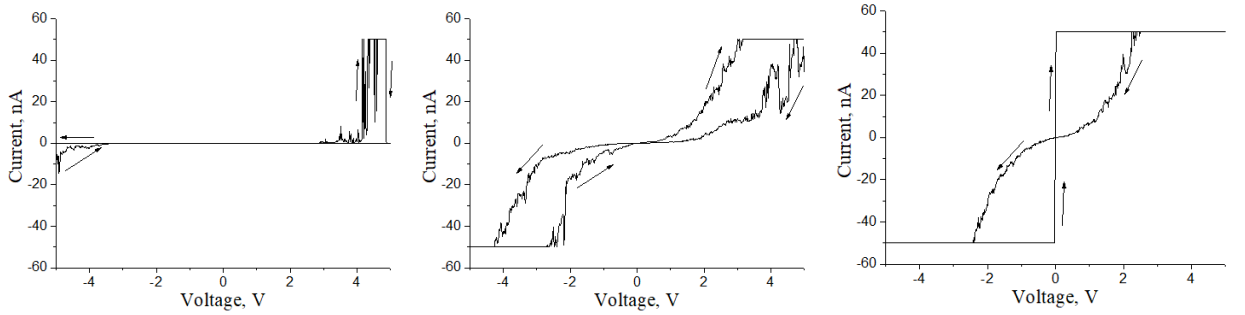



Figure 1. SEM-image of the VA CNT experimental sample.




(a) (b) (c)

Figure 2. CVC of a single VA CNT obtained by current spectroscopy at ±4 V voltage for: (a) graphite probe, (b) Pt probe, (c) W probe.




(a) (b) (c)

Figure 3. CVC of a single VA CNT obtained by current spectroscopy at ±7 V voltage for: (a) graphite probe, (b) Pt probe, (c) W probe.

Analysis of the CVCs obtained by Pt and W probes showed that the highest value of the ratio in the high- and low-resistance states of VA CNT is observed when using the W probe due to the minimum resistance in the low-resistance state both at small (Fig. 2b,c) and at higher voltages (Fig. 3b,c). This dependence is also associated with a lower work output W (4.5 eV) than Pt (5.3 eV).

Thus, in this paper an experimental study of the effect of the upper electrode on the memristor properties of strained carbon nanotubes was carried out. It is shown that the material of the upper electrode affects the switching voltage of the memristor structure based on VA CNT. The best results are shown by the W upper electrode. The obtained results can be used to create non-volatile storage devices based on aligned carbon nanotubes. The results were obtained using the equipment of the Research and Education Center and the Center for collective use "Nanotechnologies" of Southern Federal University.

The reported study was funded by RFBR according to the research project No. 16-29-14023 ofi_m.

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